HIGH VOLTAGE THIN LAYER DEVICES (RESURF DEVICES)

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ABSTRACT

The application of a somewhat unusual diode structure opens the possibility to make novel kinds of high voltage devices even with very thin epitaxial or implanted layers. In the new structures crucial changes in the electric field distribution take place at or at least near the surface. The acronym RESURF (REduced SURface Field) was chosen.

BASIC STRUCTURE

The basic structure consists of a high-ohmic P^- substrate with an epitaxial N^- layer on it, which is laterally bounded by a P^+ diffusion[1]. The diode thus formed consists of two parts: one horizontal P^-N junction and a vertical P^+N junction. Considering these parts as one-dimensional junctions, the vertical one has the lower breakdown voltage, which is determined by the doping concentration of the epitaxial layer (e.g. 370 V for $N_{epi} = 6.10^{14}$). The breakdown voltage of the horizontal junction is considerably higher due to the high-ohmic substrate (1150 V for the example of fig. 1).

For thick epitaxial layers the depletion at the surface of the vertical P^+N junction is not influenced by the horizontal junction and hence breakdown voltage is determined by the P^+N junction. The electric field pattern along the surface and the axis of symmetry for this case is given in fig. 1a. Going to thinner layers however, the depletion of the vertical P^+N junction becomes more and more reinforced by the horizontal junction. Consequently at the same applied voltage, the depletion stretches along the surface over a much longer distance than would be expected according to a simple one-dimensional calculation. Now the electric field at the surface is far below the critical field (Fig. 1b) and a much higher voltage can be applied before breakdown occurs. Beneath a certain thickness of the epitaxial layer, this REduced SURface Field will not reach the critical value not even at high voltages and hence

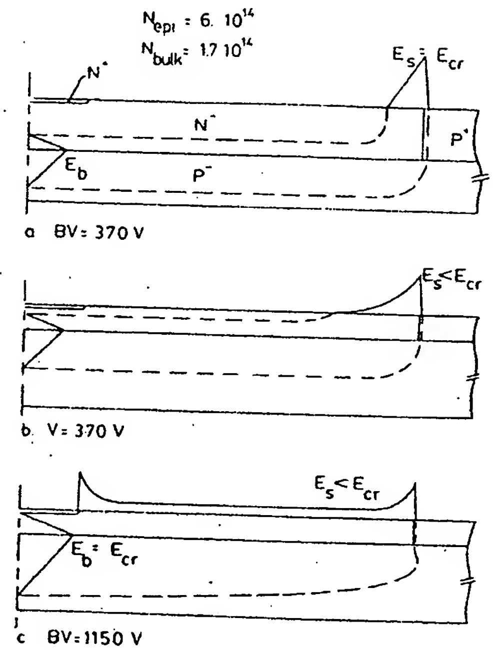

Fig. 1. Representation of the electric field distribution.
a. for a thick epitaxial layer (370 V),
b. for a thin epitaxial layer (370 V),
c. for a thin epitaxial layer (1150 V).

surface breakdown has been eliminated. Now the breakdown of the diode is determined by the horizontal junction and thus the ideal bulk breakdown can be reached. (Fig. 1c). However, since the epitaxial layer is fully depleted a new effect arises. Due to the curvature of the N^+ contact the electric field will strongly increase. For very thin epitaxial layers the effect becomes so pronounced that

the electric field peak at the edge of the N^+ region is larger than the field in the bulk.
Now corner breakdown will occur at a voltage which is lower than the ideal bulk breakdown voltage. Two-dimensional numerical calculations show that a symmetrical electric field distribution at the surface is obtained, when $N_{epi} \cdot d_{epi} = 10^{12}$ at/cm^2, where N_{epi} and d_{epi} are the doping concentration and the thickness of the epitaxial layer, respectively. For the structure as discussed so far, a plot of breakdown voltage versus epitaxial layer thickness is given.

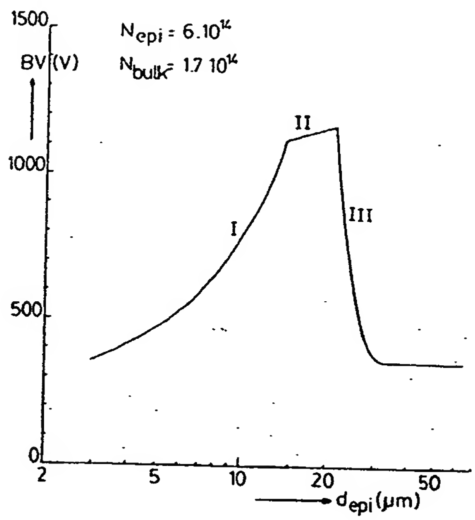

Fig. 2. Breakdown voltage as a function of epitaxial layer thickness. In region II breakdown takes place at the horizontal junction. In region I and III breakdown takes place at the N^+ or P^+ regions, respectively.

LATERAL BIPOLAR TRANSISTOR

A minor change in the diode structure leads to a high voltage bipolar transistor. Simply by introducing an N^+ emitter diffusion in the P^+ isolation region, a transistor is obtained. (Fig. 3). To make transistor action more efficient, it is preferred to enlarge the P^+ region by a shallow P^+ base diffusion.

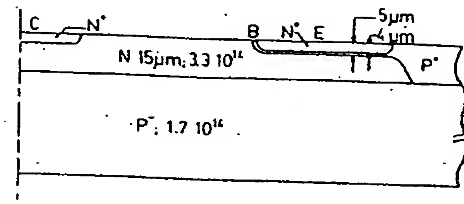

Fig. 3. Cross-section of a lateral bipolar transistor.

The high-ohmic N^- region together with the N^+ contact diffusion forms the collector zone of the transistor.
The transistor action itself mainly takes place in the top-layer of the structure. By increasing the resistivity of the substrate, high emitter-collector breakdown voltages can be obtained. The P^+ base-diffusion need not necessarily be connected to the isolation region but can also be made as a floating island in the N^- layer.
Fig. 4 presents the current-voltage characteristics of an NPN lateral transistor made in an epitaxial layer with a thickness of 15 μm.

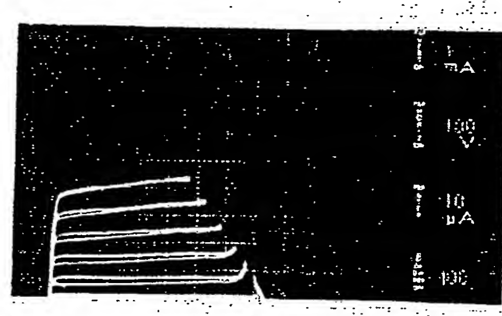

Fig. 4. Common emitter output characteristics of a lateral bipolar transistor. $BV_{CEO} = 730$ V $BV_{CBO} = 850$ V.

VERTICAL BIPOLAR TRANSISTOR

Fig. 5 shows a cross-section of a vertical PNP transistor. The only difference with a conventional structure is an additional N^- layer which is laterally bounded by a P^+ diffusion.

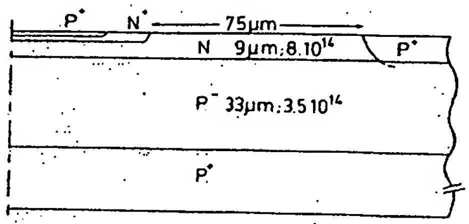

Fig. 5. Cross-section of a vertical bipolar PNP transistor.

In contrast with the lateral transistor, the Resurf N^- layer, is now a part of the base region. By a proper choice of dimensions and doping concentration of the N^- layer, the electric field distribution at the surface can be such that breakdown will take place at the horizontal N^-P^- junction. In this way even with shallow base diffusions very high collector-base breakdown voltages can be obtained.
Fig. 6 shows the measured I-V characteristics of such a PNP transistor.

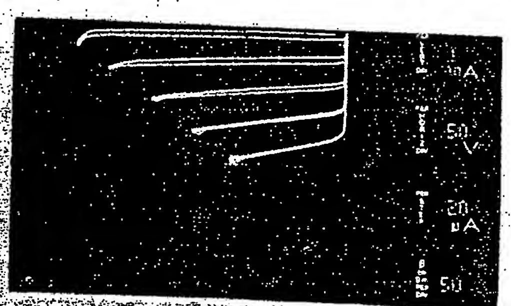

Fig. 6. Vertical PNP Resurf transistor made according to the principle described. $BV_{CEO} = 470$ V; $BV_{CBO} = 520$ V.

JUNCTION FET

In conventionally fabricated J-Fets a high gate-to-drain breakdown voltage is inherently coupled with a thick high-ohmic layer in order to be able to accommodate the applied reverse voltage at the drain end.
The use of Resurf layers opens the possibility of making high-voltage J-Fets with a low pinch-off voltage and a high current-carrying capability, in relatively thin epitaxial or implanted layers.

Fig. 7 shows a cross-section of a thin layer Resurf J-Fet.

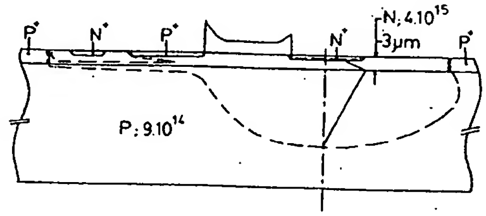

Fig. 7. Cross-section of a Resurf J-Fet.

The extension of the depletion layer in the substrate as well as the electric field distribution in the bulk and at the surface of the drain end are depicted.
I-V characteristics of some experimental samples made with non-optimized photo masks are shown in Figs. 8 and 9.

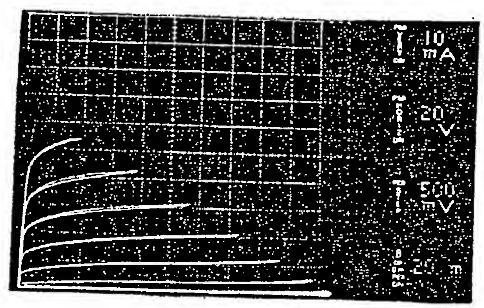

Fig. 8. Resurf J-Fet made in 3 µm thick epitaxial layer. $BV_{S-D} \leq 230$ V.

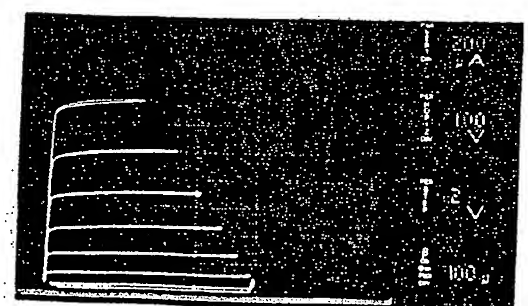

Fig. 9. Resurf J-Fet made in a 15 µm thick epitaxial layer.

CONCLUSION

The use of high-ohmic substrates with relatively thin epitaxial layers on them, which meet the requirements mentioned in this paper (i.e. $N_{epi} \times d_{epi} \cong 10^{12}$ at/cm^2) opens the possibility of making high-voltage devices whose structure and operation, in particular the electric field distribution, differ essentially from those of conventional devices.

Ref.
1) Late News Paper, ESSDERC '79 München.